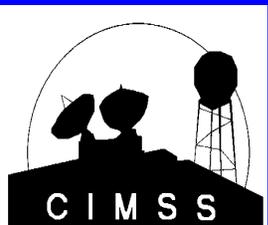


# NOAA/NESDIS GOES-R High Spectral Sounder Data Compression Studies

Bormin Huang, Allen Huang and Kevin Baggett

Cooperative Institute for Meteorological Satellite Studies  
University of Wisconsin-Madison

May 22, 2003



## Lossless Compression Studies:

- 3D IWT + 3D EZW + Arithmetic Coding  
(*EZW: Embedded Zerotree Wavelet, 1993*)
- 3D IWT + 3D SPIHT + Arithmetic Coding  
(*SPIHT: Set Partitioning in Hierarchical Trees, 1995*)
- 3D IWT + 3D SPIHT + Prefix/Huffman Coding

## Lossy Compression Studies:

- 3D IWT + 3D EZW + Arithmetic Coding
- 3D IWT + 3D SPIHT + Arithmetic Coding
- 3D IWT + 3D LTW + Arithmetic Coding  
(*LTW: Lower-tree wavelet, 2003*)
- Locally Partitioned Vector Quantization (2003)

# Wavelet Transform Overview

The wavelet transform involves the scaling function  $\varphi(x)$ , the wavelet function  $\psi(x)$  and their duals  $\tilde{\varphi}(x)$  and  $\tilde{\psi}(x)$ . These functions satisfy dilation equations, which are:

$$\varphi(x) = \sqrt{2} \sum_k H_k \varphi(2x - k)$$

$$\psi(x) = \sqrt{2} \sum_k G_k \varphi(2x - k)$$

$$\tilde{\varphi}(x) = \sqrt{2} \sum_k \tilde{H}_k \tilde{\varphi}(2x - k)$$

$$\tilde{\psi}(x) = \sqrt{2} \sum_k \tilde{G}_k \tilde{\varphi}(2x - k)$$

The coefficients  $H_k$ ,  $G_k$ ,  $\tilde{H}_k$  and  $\tilde{G}_k$  represent the coefficients of the filters  $H$ ,  $G$ ,  $\tilde{H}$  and  $\tilde{G}$  respectively. The basis functions are translated and dilated versions of the above functions and are defined as

$$\varphi_{j,k}(x) = 2^{2j} \varphi(2^j x - k)$$

$$\psi_{j,k}(x) = 2^{2j} \psi(2^j x - k).$$

A function represented at resolution level  $j+1$ :

$$f(x) = \sum_k \alpha_{j+1,k} \varphi_{j+1,k}(x)$$

can be decomposed into its low pass and high pass components:

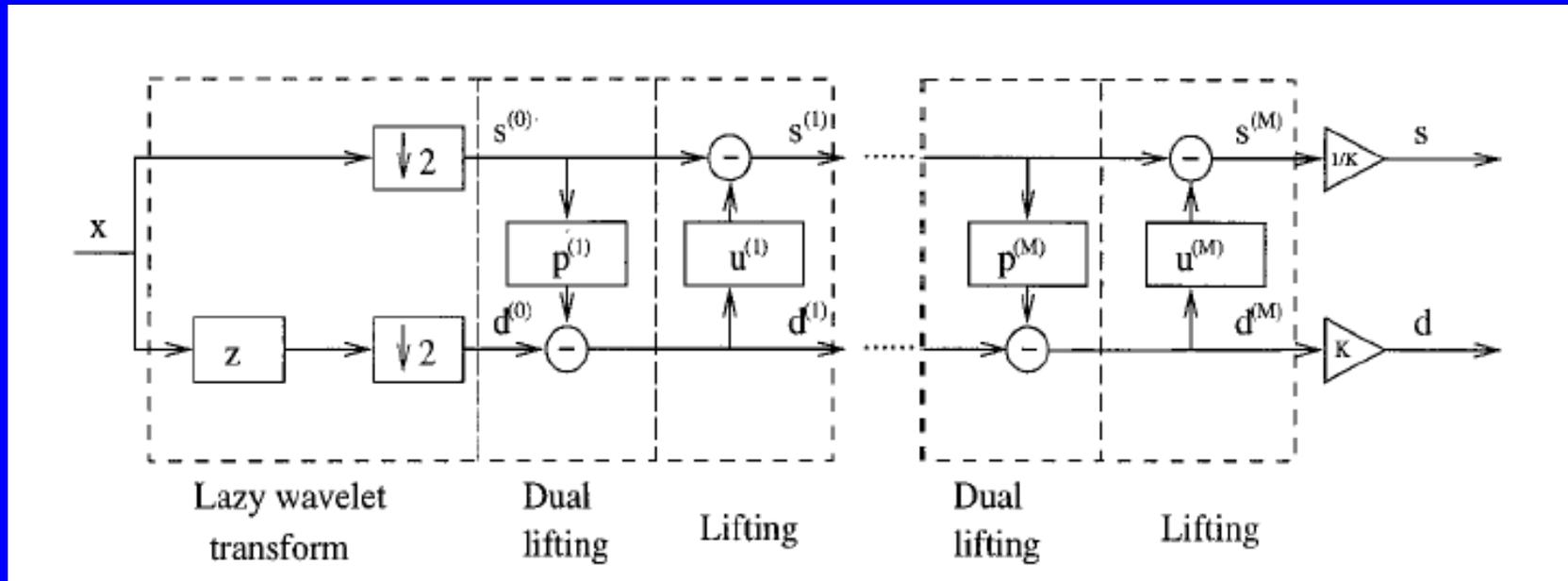
$$f(x) = \sum_l \alpha_{j,l} \varphi_{j,l}(x) + \sum_l \beta_{j,l} \psi_{j,l}(x)$$

where the desired coefficients  $\alpha_{j,l}$  and  $\beta_{j,l}$  can be obtained by the Fast Wavelet Transform:

$$\alpha_{j,l} = \sqrt{2} \sum_k \tilde{H}_{k-2l} \alpha_{j+1,k}$$

$$\beta_{j,l} = \sqrt{2} \sum_k \tilde{G}_{k-2l} \alpha_{j+1,k}.$$

# 1-D Integer Wavelet Transform



The lazy wavelet transform is then given by

$$s^{(0)}[n] = x[2n],$$

$$d^{(0)}[n] = x[2n + 1].$$

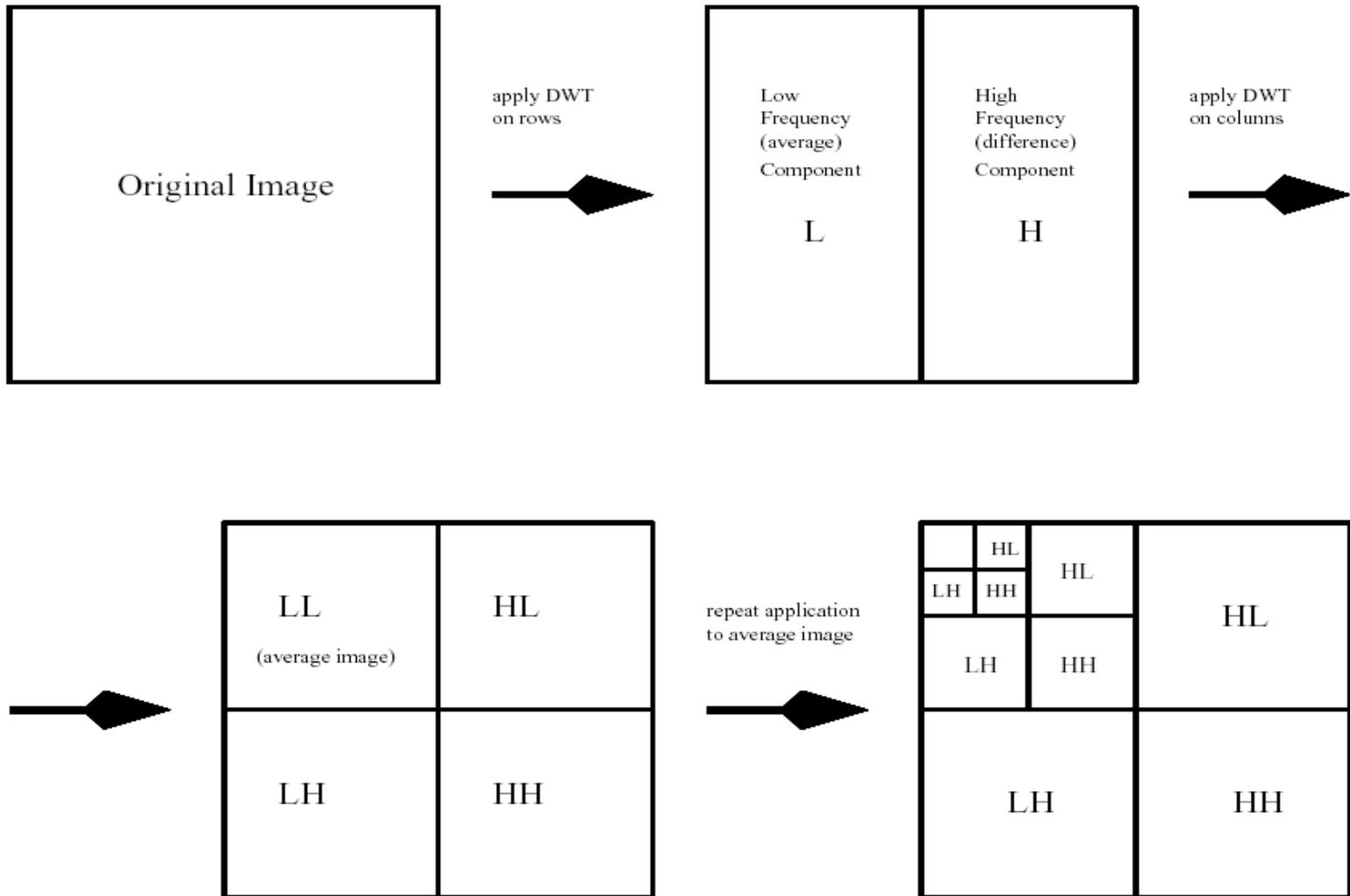
Next, alternating dual-lifting and lifting steps are applied to obtain

$$d^{(i)}[n] = d^{(i-1)}[n] - \sum_k p^{(i)}[k] s^{(i-1)}[n - k],$$

$$s^{(i)}[n] = s^{(i-1)}[n] - \sum_k u^{(i)}[k] d^{(i)}[n - k],$$

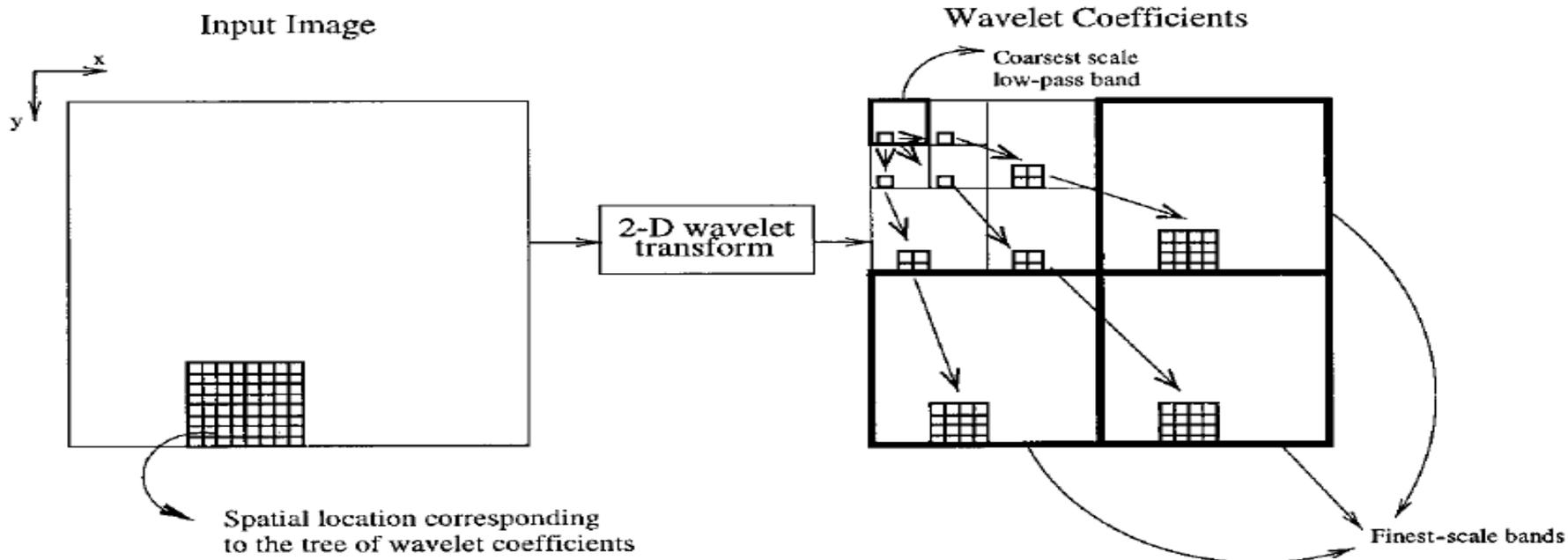
where the coefficients  $p^{(i)}[k]$  and  $u^{(i)}[k]$  are computed by use of factorization of a polyphase matrix.

# 2-D Wavelet Transform

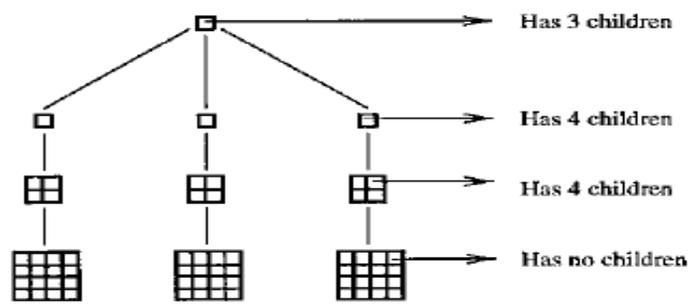


Two-dimensional DWT

# 2-D Wavelet Tree Coding (EZW, SPIHT, LTW)



Tree Representation of Wavelet Coefficients



Two-dimensional dyadic wavelet decomposition.

# 3-D Wavelet Tree Coding (EZW, SPIHT, LTW)

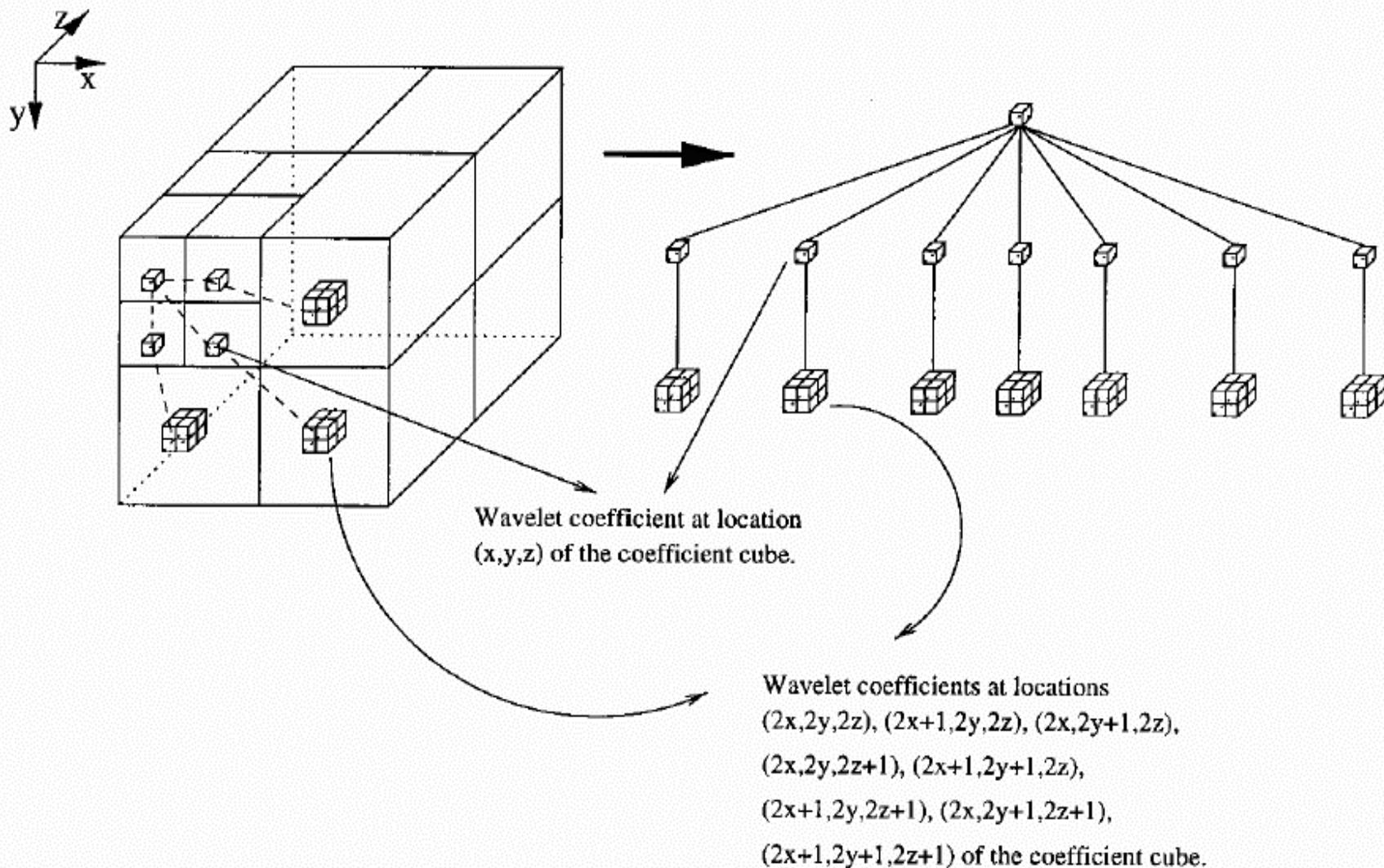
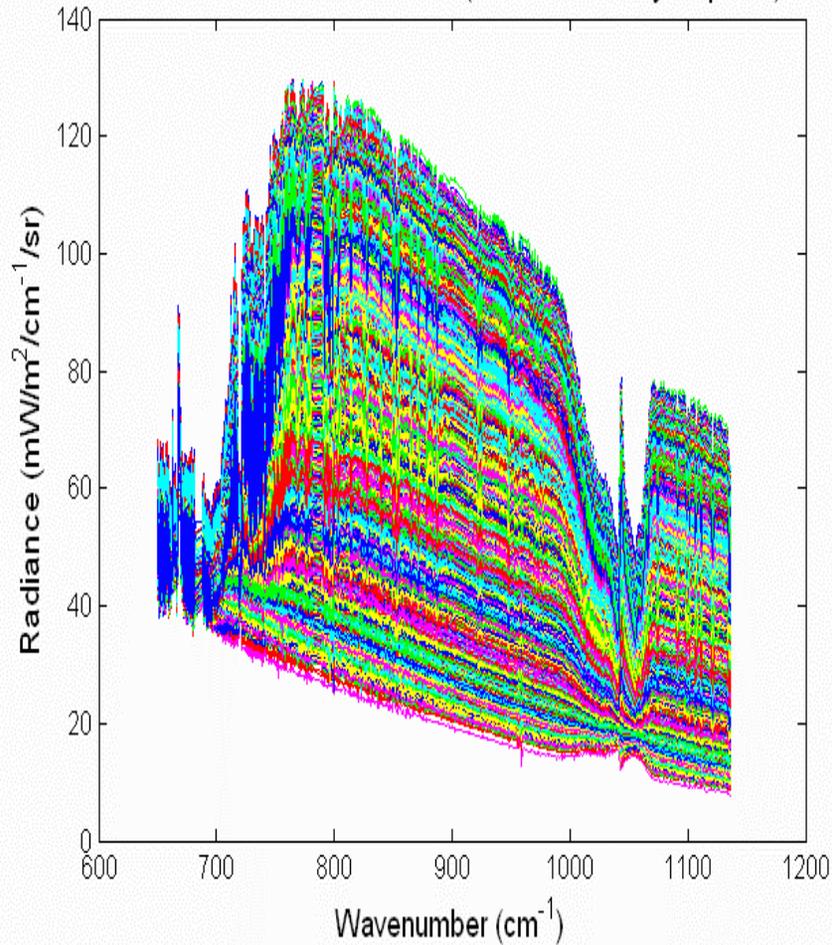


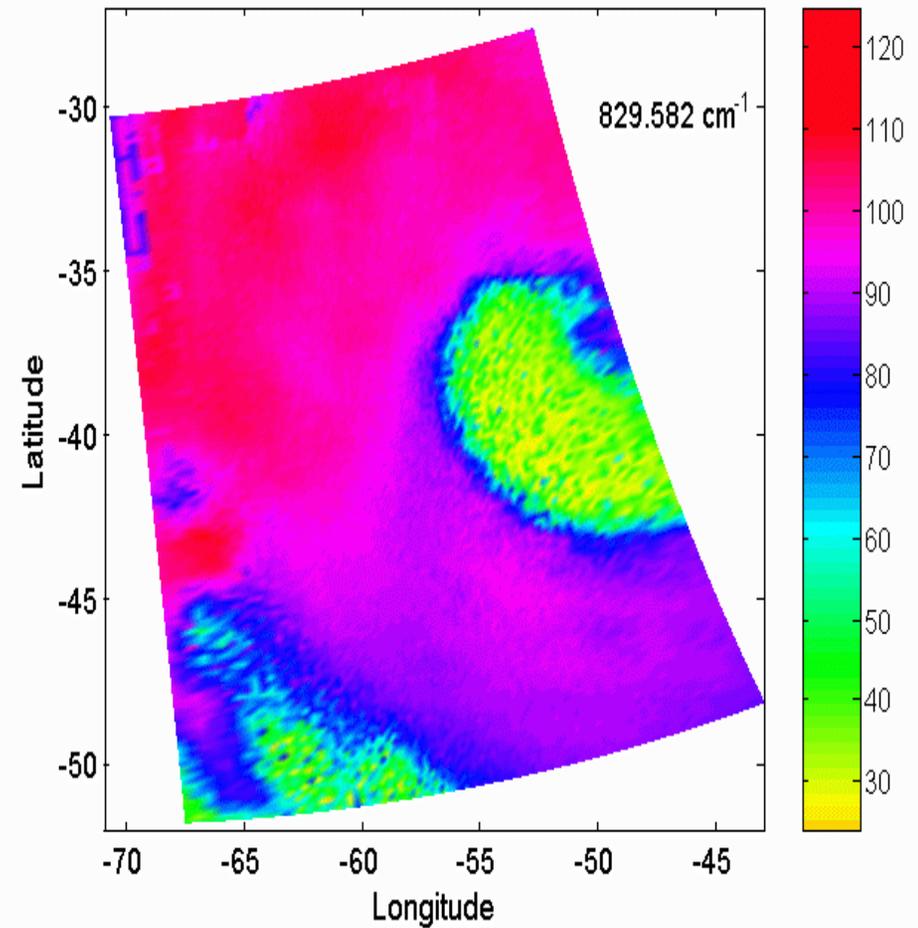
Diagram of the 3-D tree structure.

# Simulated AIRS Granule 176

Simulated AIRS Granule 176 (135 scanlines by 90 pixels)

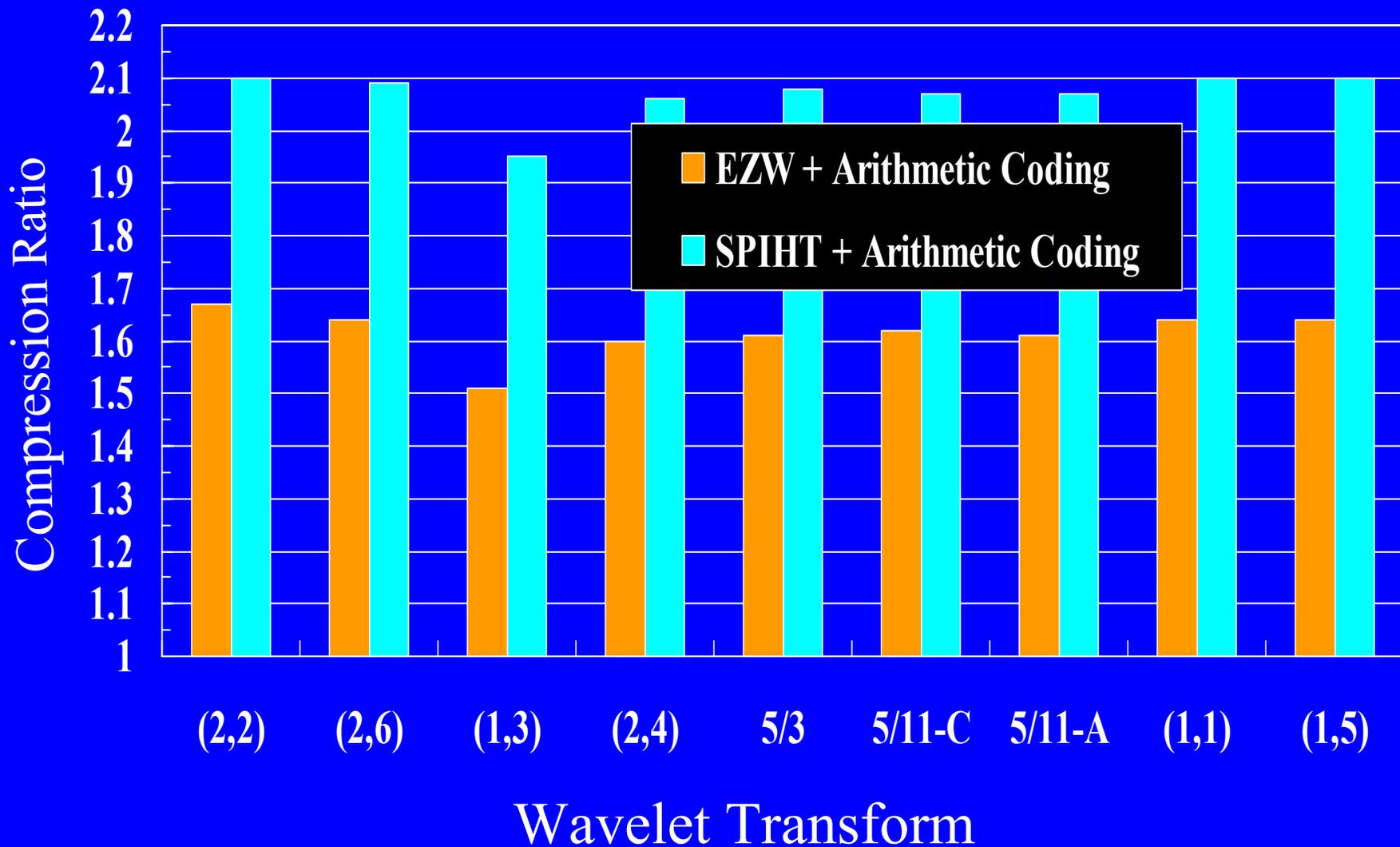


Simulated AIRS Radiances, Granule 176 (April 1, 2002)



# Lossless Compression 3D EZW vs. 3D SPIHT

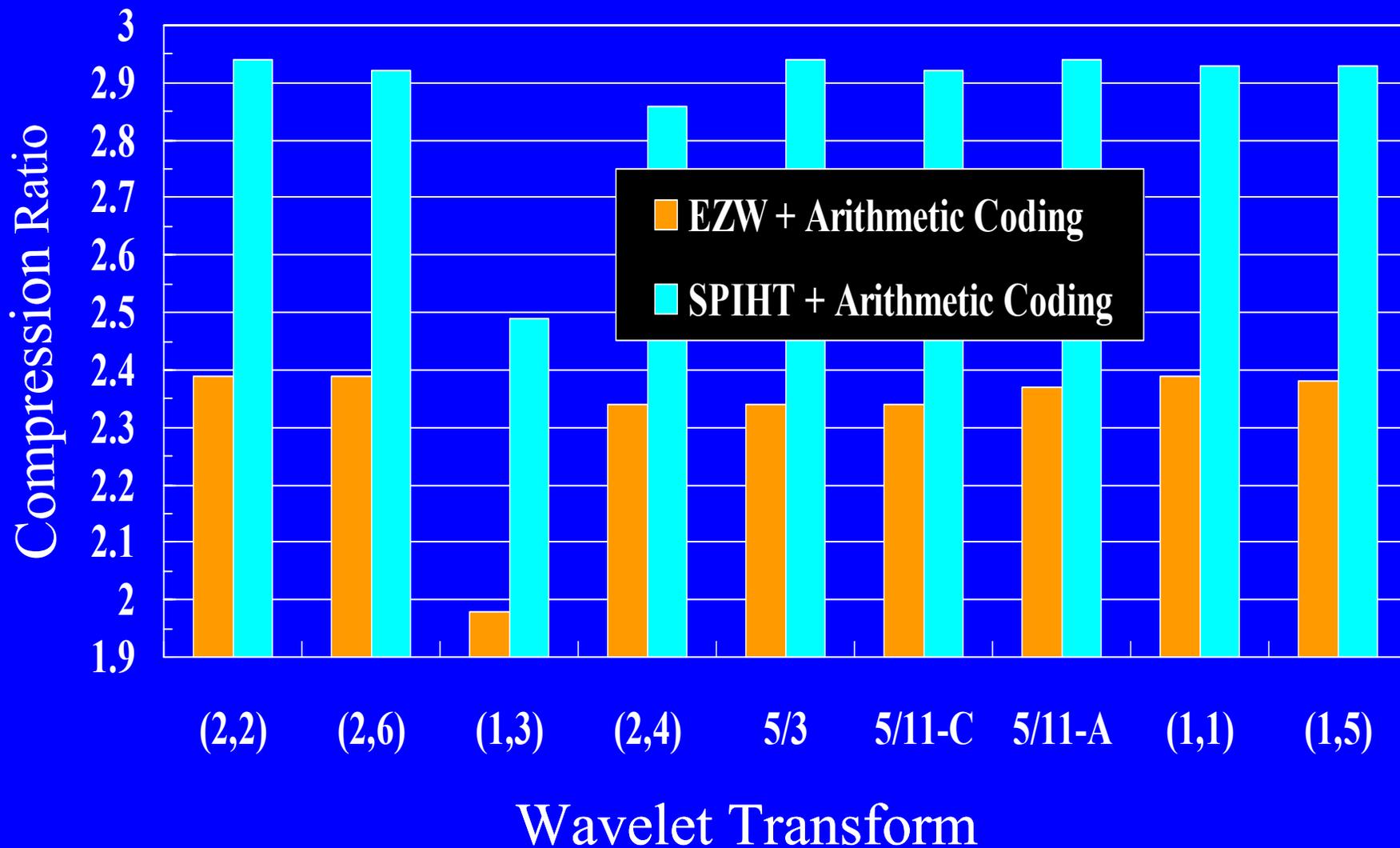
Simulated AIRS Granule 176 Longwave Noisy Data



# Lossless Compression

## 3D EZW vs. 3D SPIHT

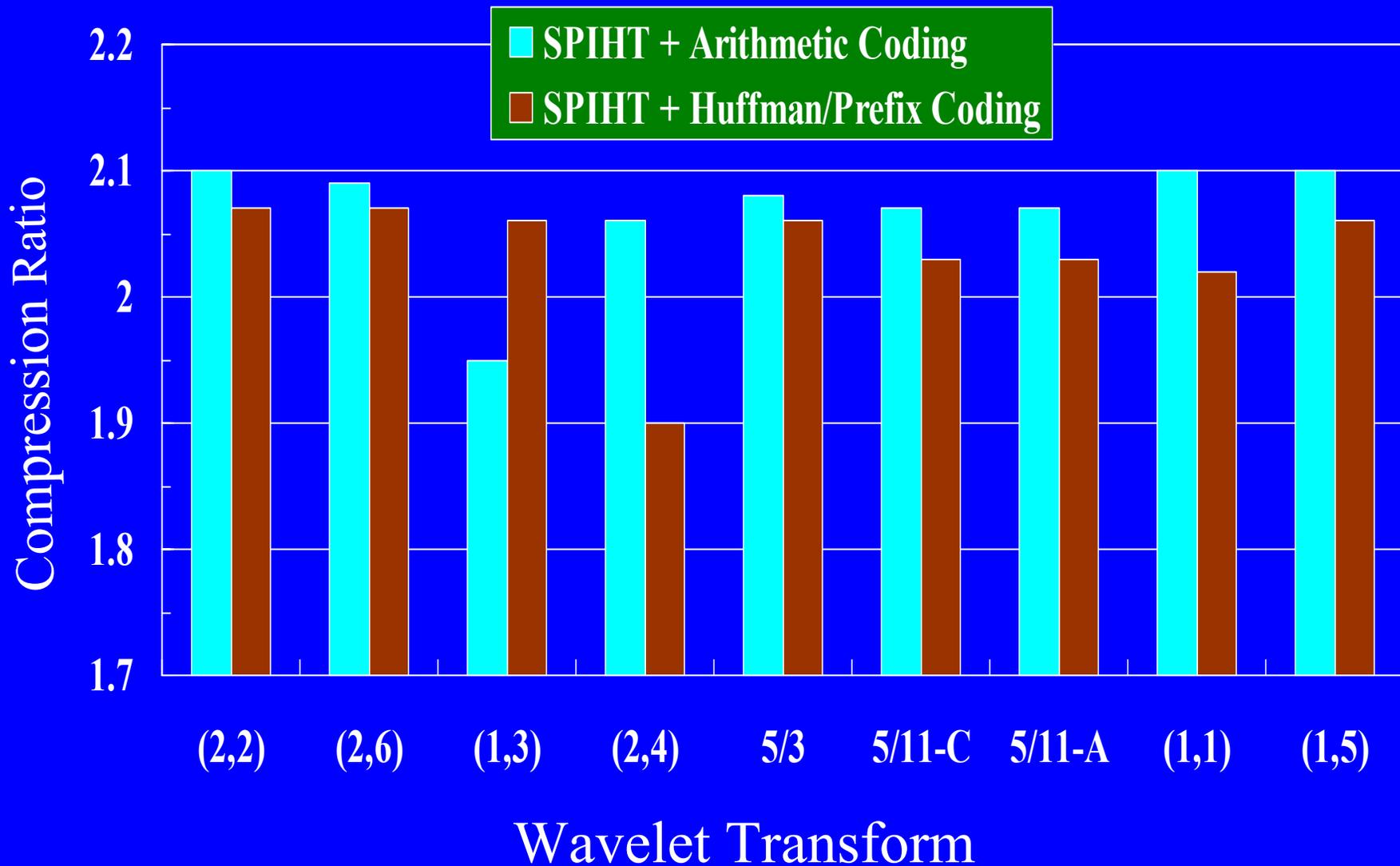
Simulated AIRS Granule 176 Midwave Noisy Data



# Lossless Compression

## Arithmetic Coding vs. Huffman/Prefix Coding

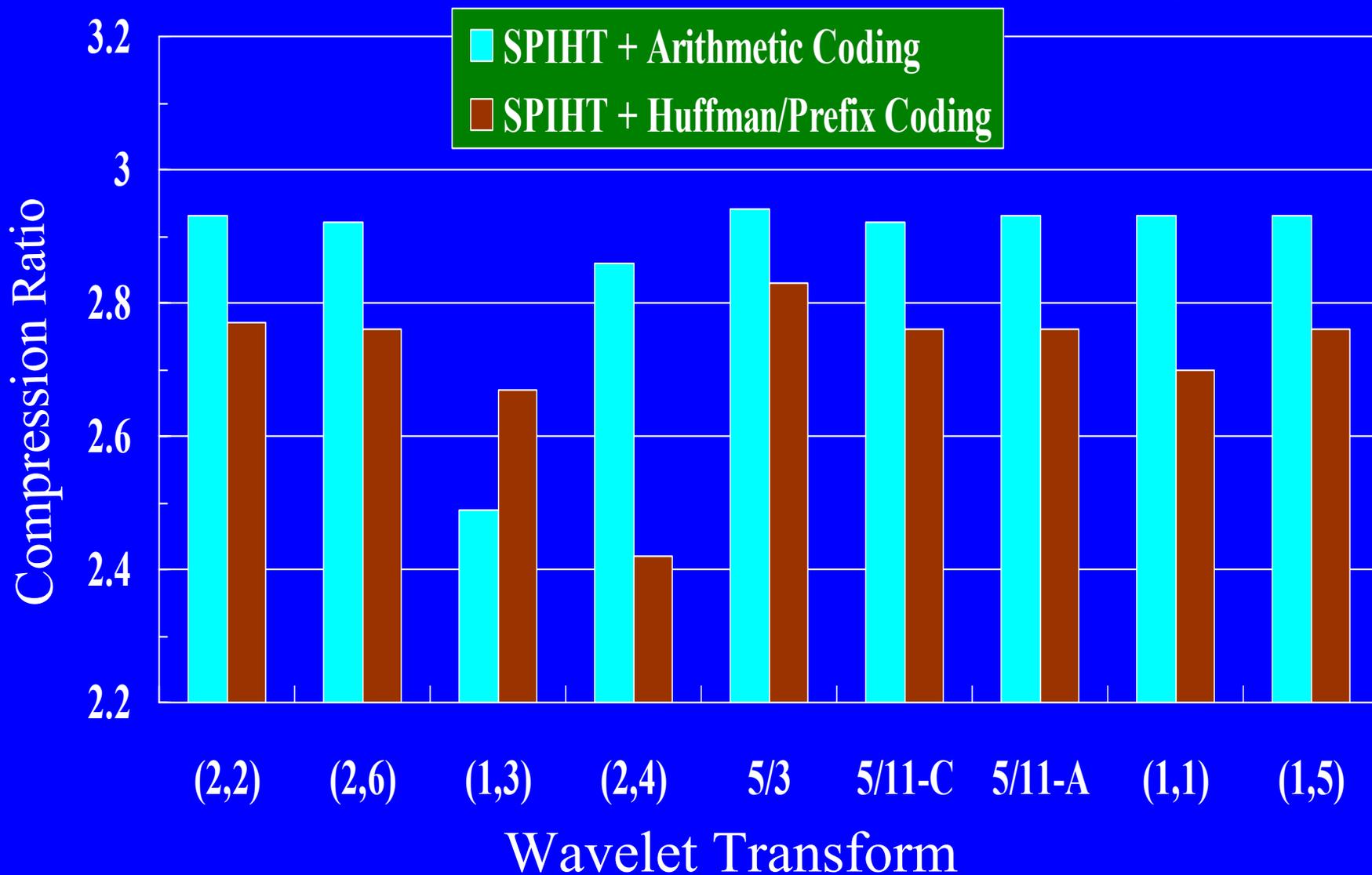
### Simulated AIRS Granule 176 Longwave Noisy Data



# Lossless Compression

## Arithmetic Coding vs. Huffman/Prefix Coding

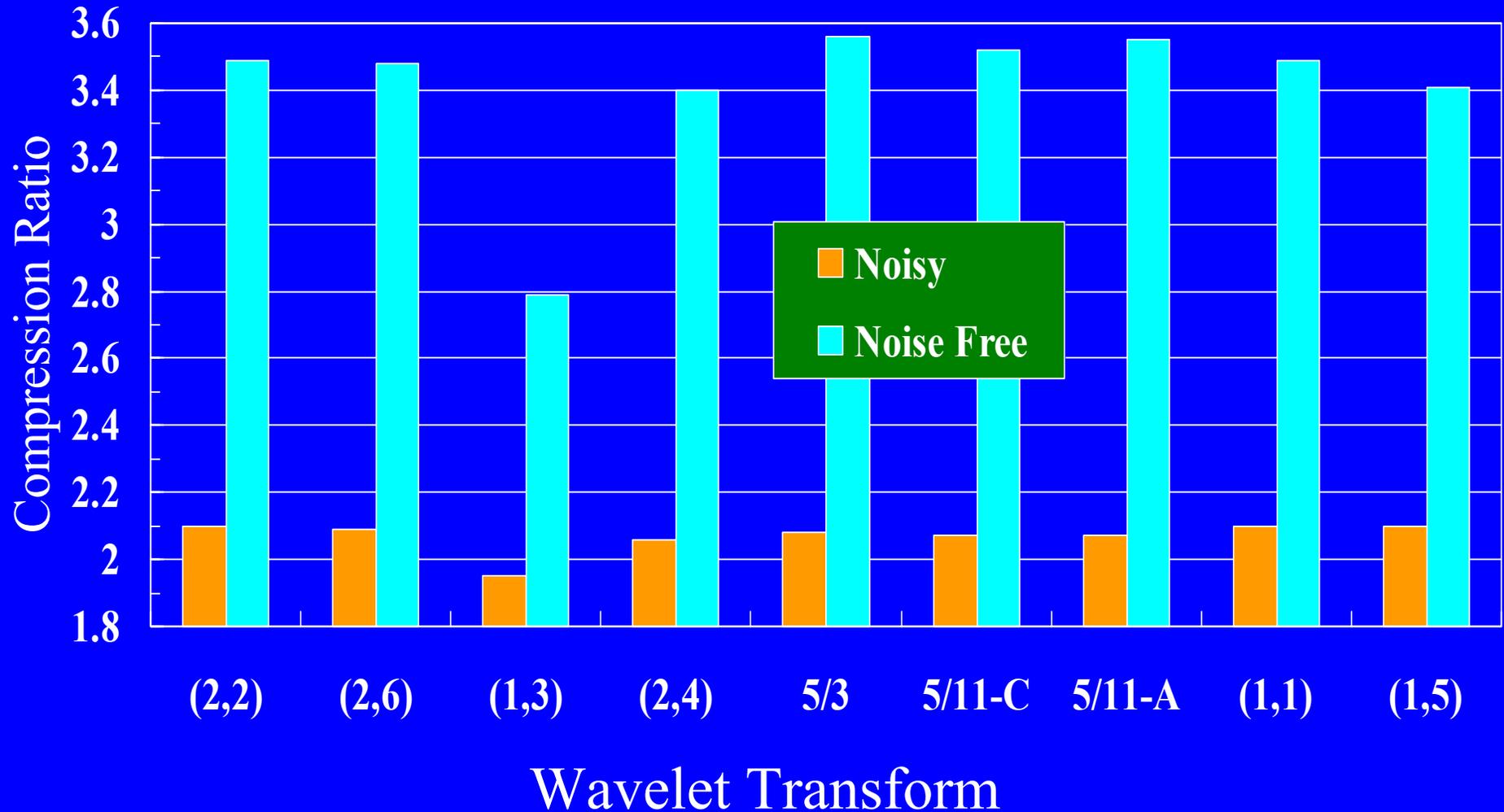
### Simulated AIRS Granule 176 Midwave Noisy Data



# 3D SPIHT Lossless Compression

Noisy vs. Noise Free

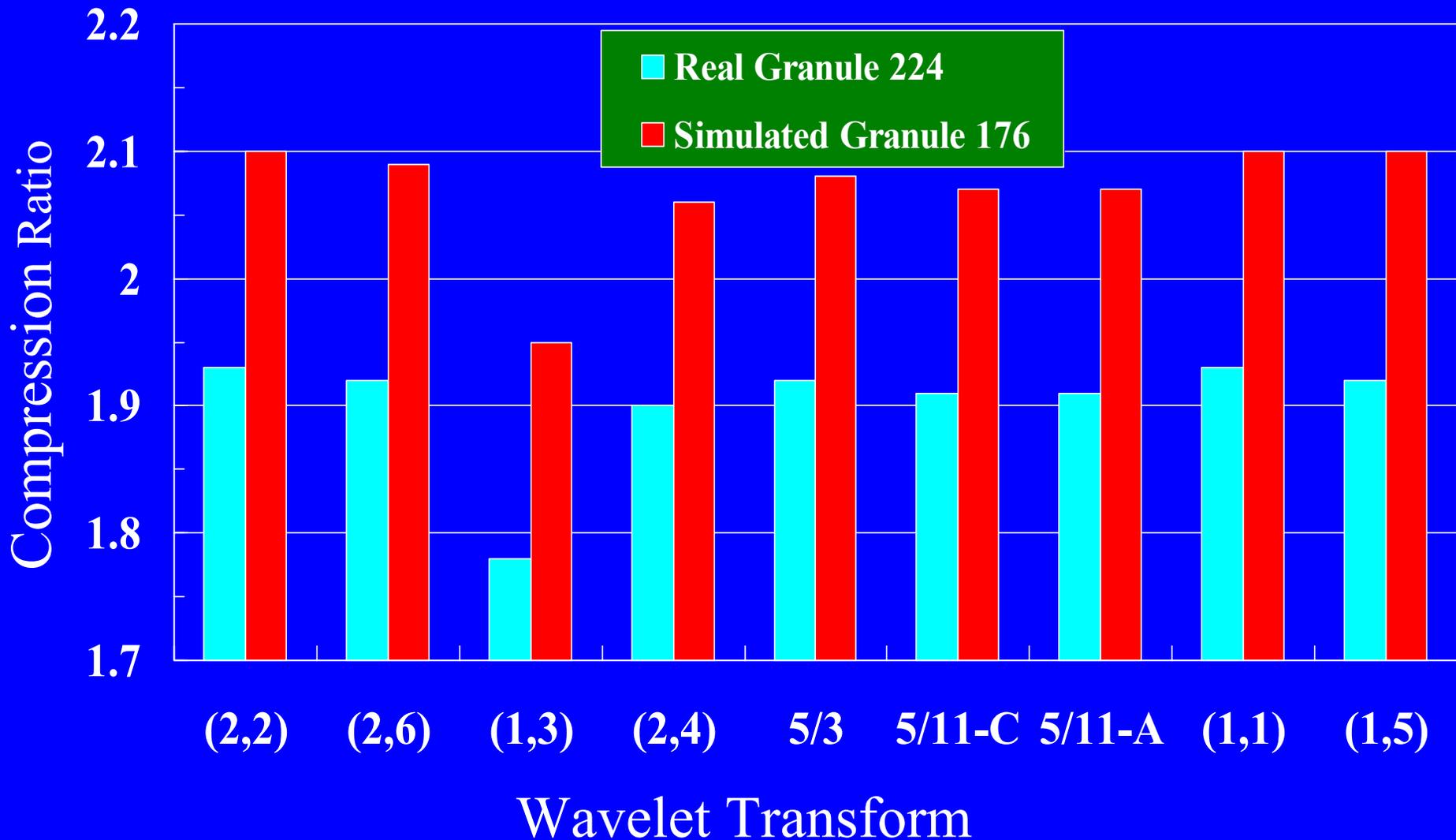
Simulated AIRS Granule 176 Longwave Data



# 3-D SPIHT Lossless Compression

Real vs. Simulated

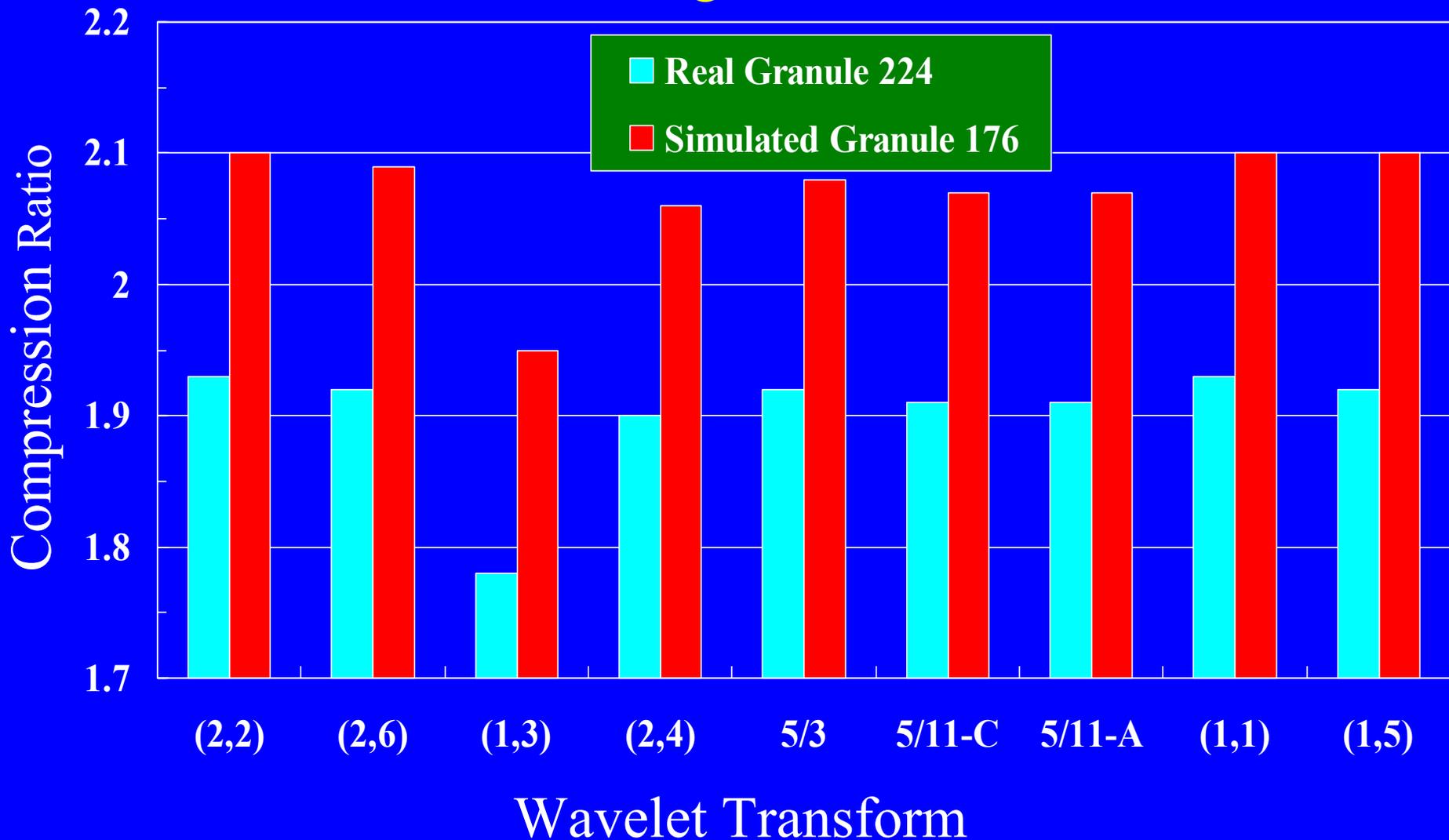
AIRS Longwave Granules



# 3-D SPIHT Lossless Compression

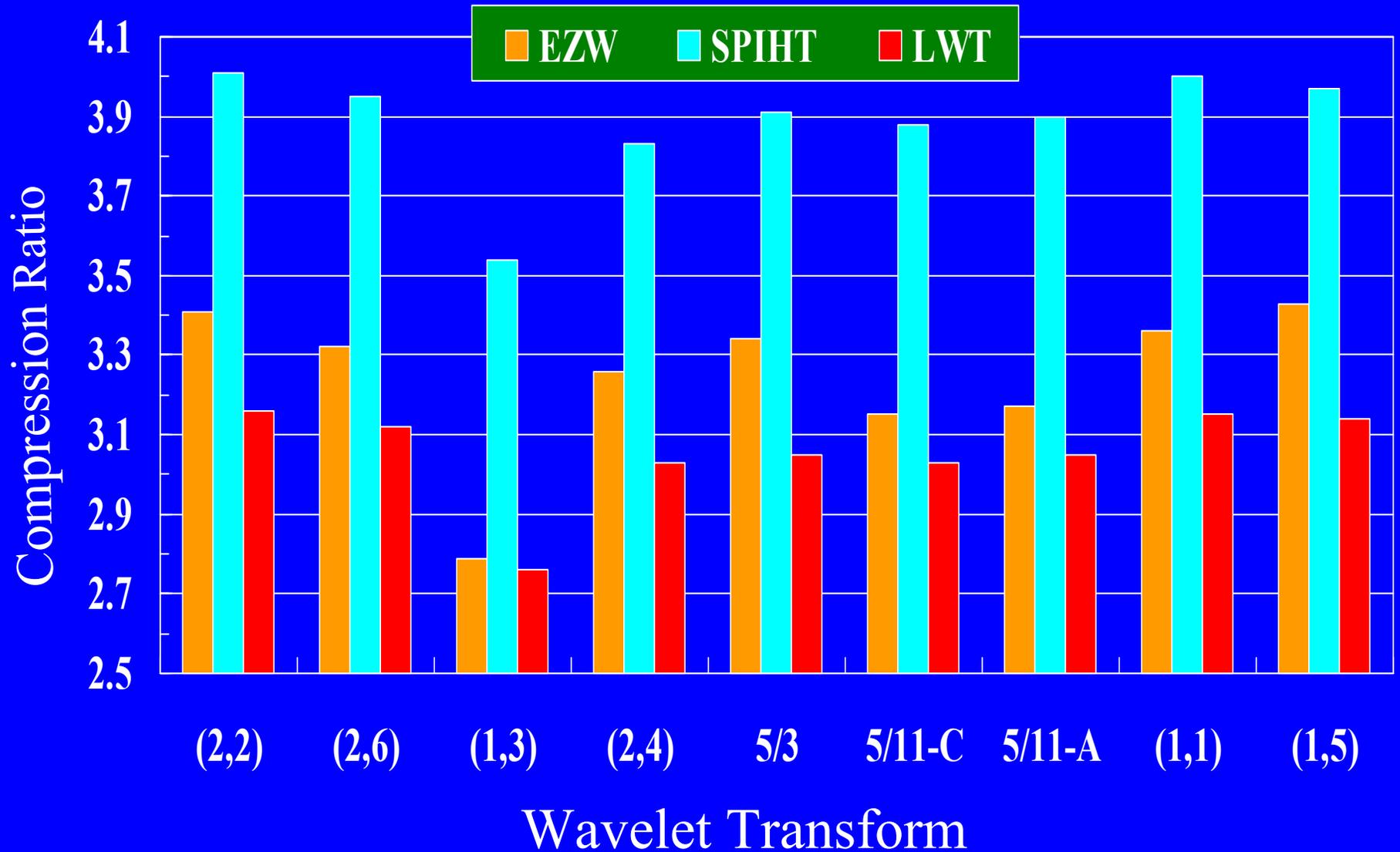
Real vs. Simulated

AIRS Longwave Granules

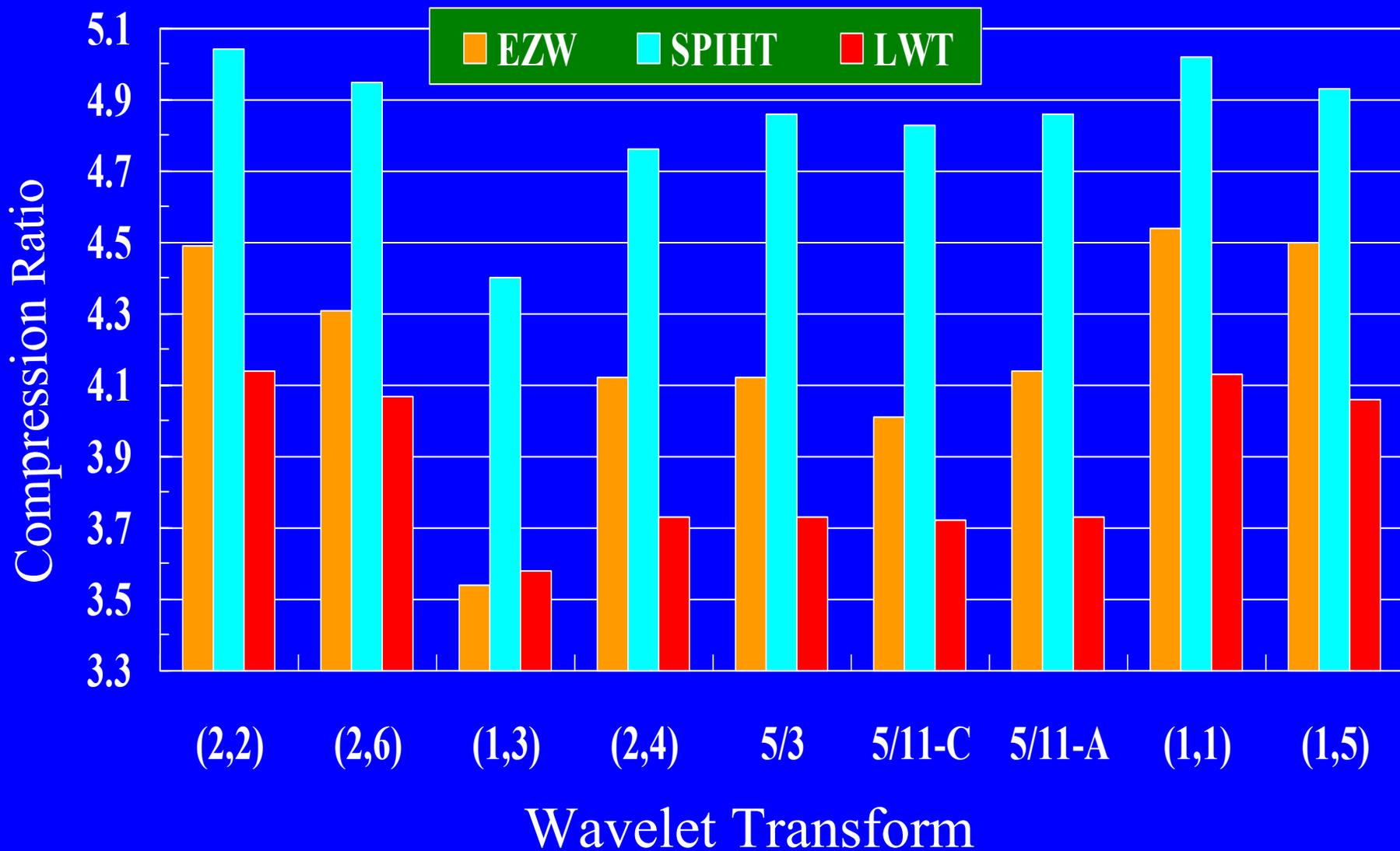


# 12-Bit Uniform Lossy Compression 3D EZW vs. 3D SPIHT vs. 3D LWT

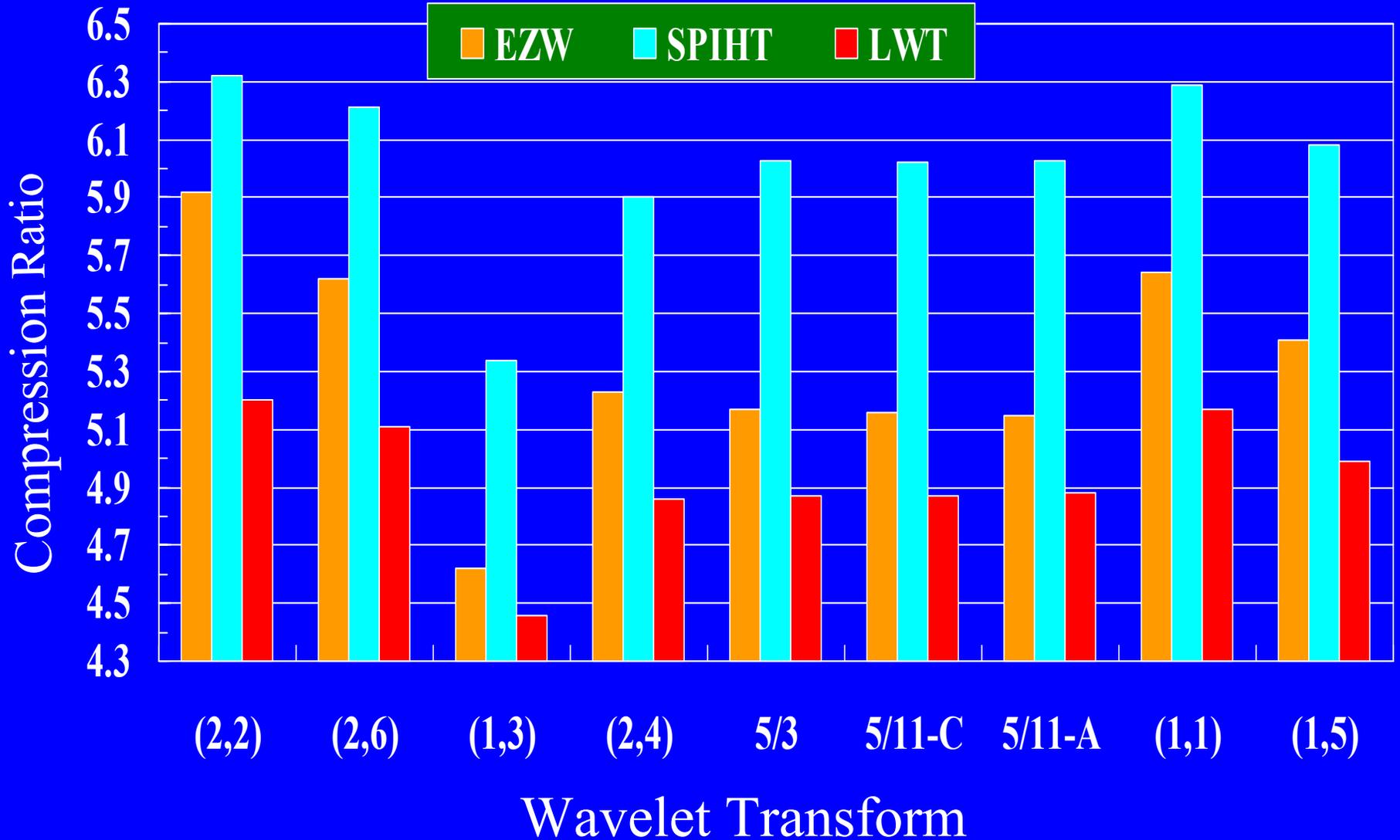
Simulated AIRS Granule 176 Longwave Noisy Data



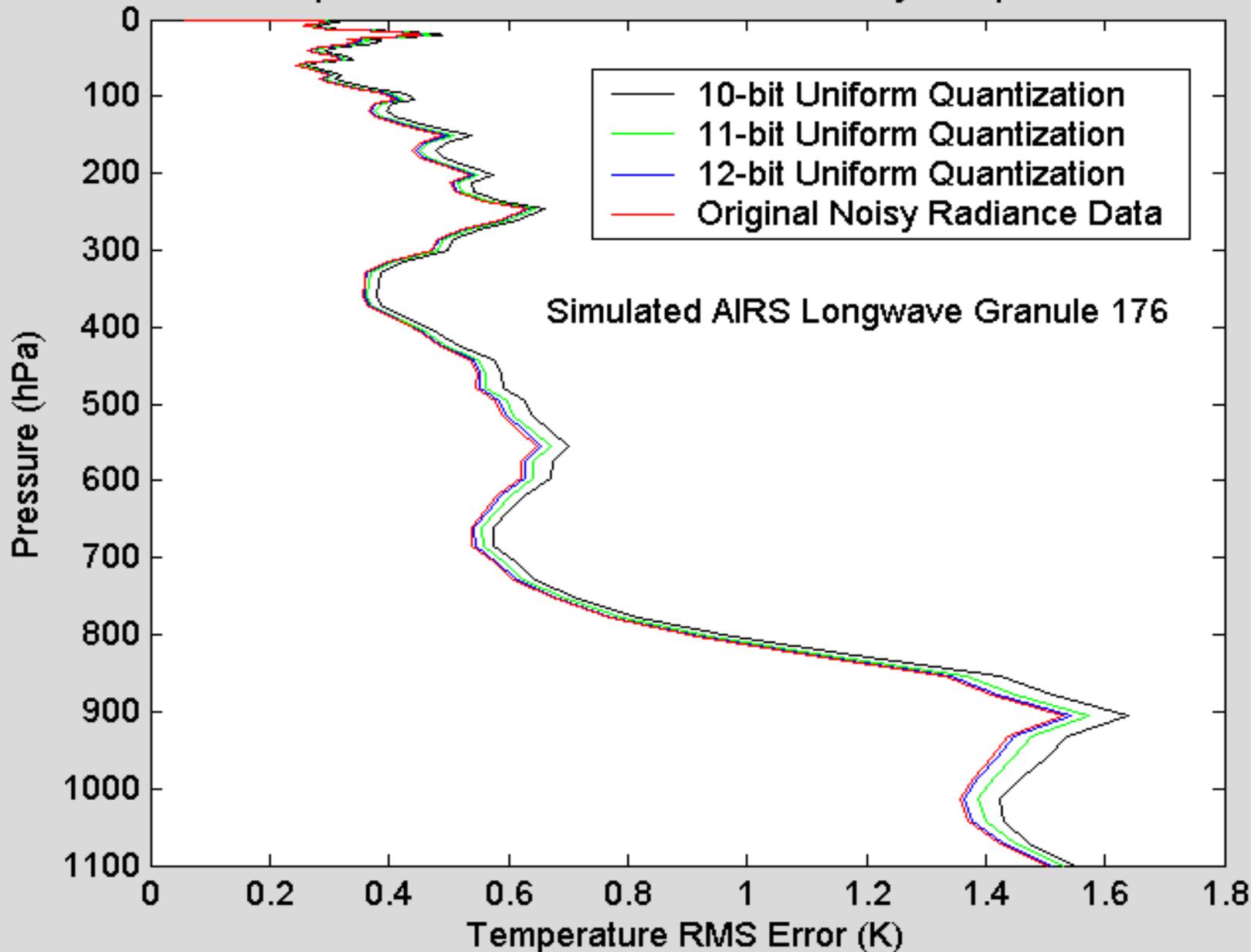
# 11-Bit Uniform Lossy Compression 3D EZW vs. 3D SPIHT vs. 3D LWT Simulated AIRS Granule 176 Longwave Noisy Data



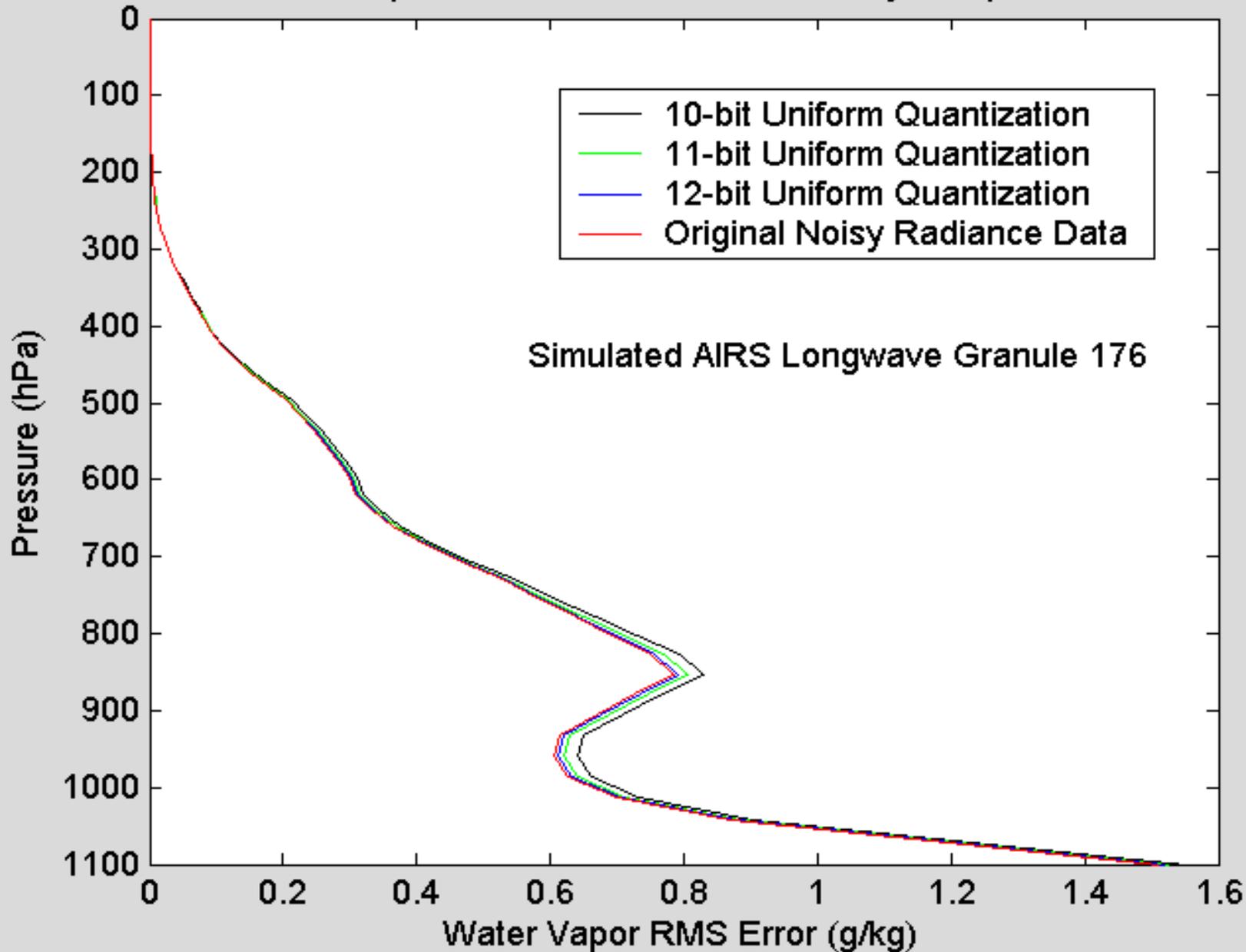
10-Bit Uniform Lossy Compression  
3D EZW vs. 3D SPIHT vs. 3D LWT  
Simulated AIRS Granule 176 Longwave Noisy Data



# Temperature RMS Error for Uniform Lossy Compression



### Water Vapor RMS Error for Uniform Lossy Compression



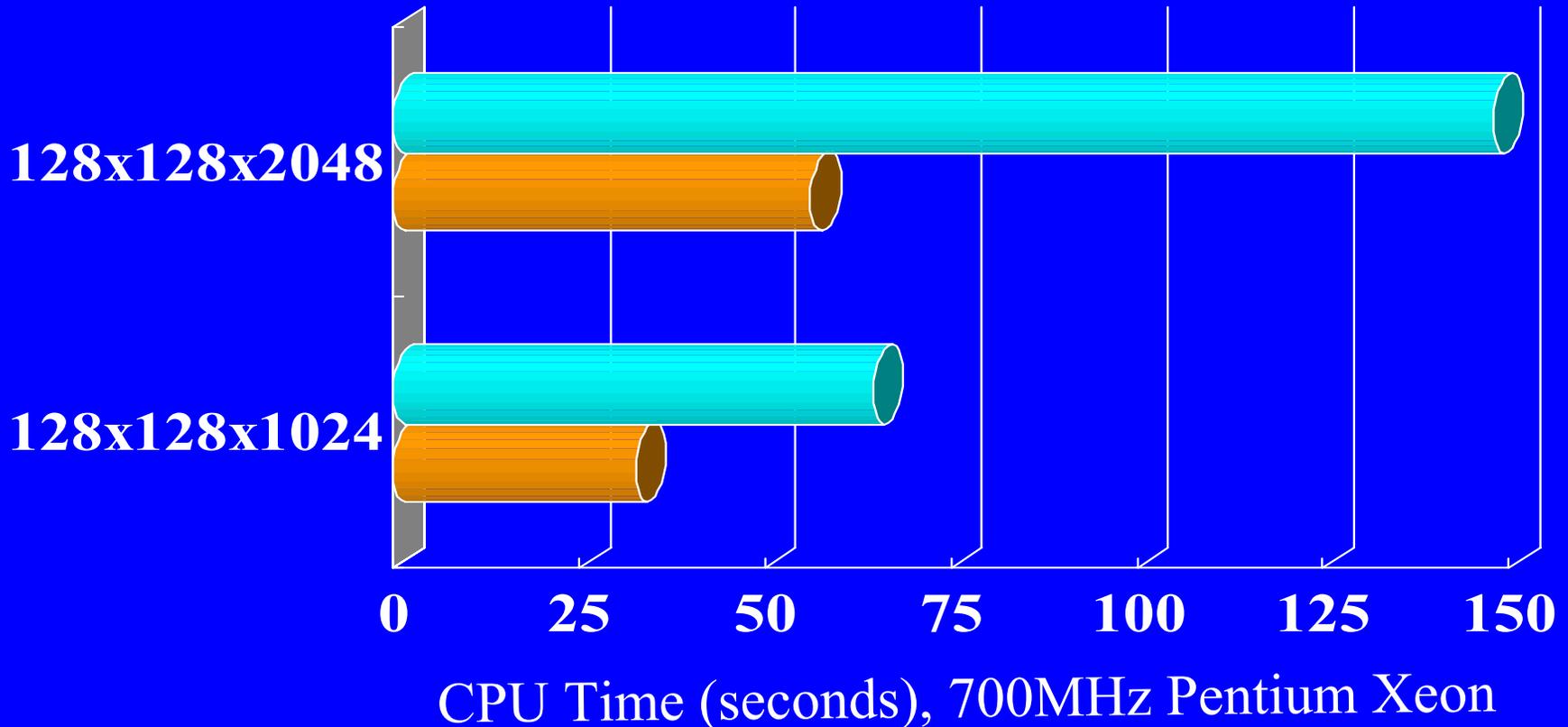
# 3-D SPIHT Lossless Compression

## Regular vs. Irregular Data Size

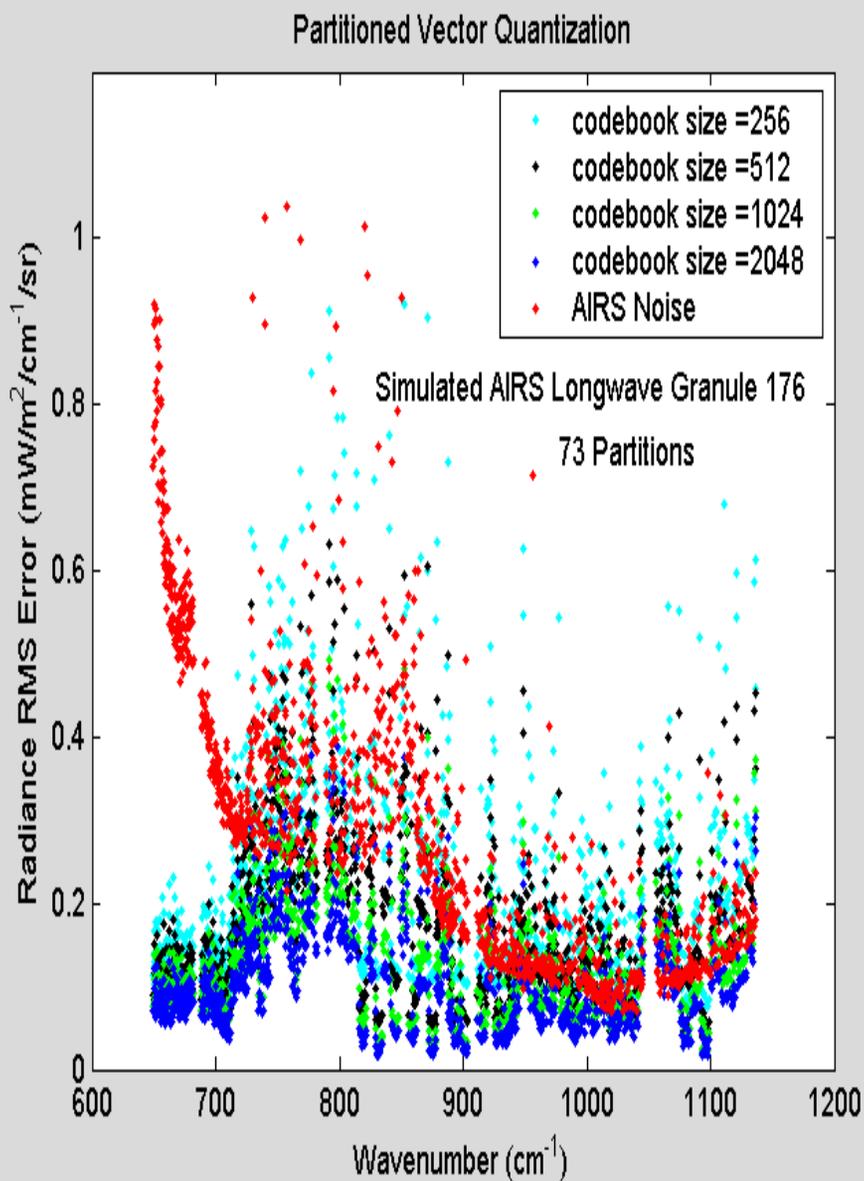
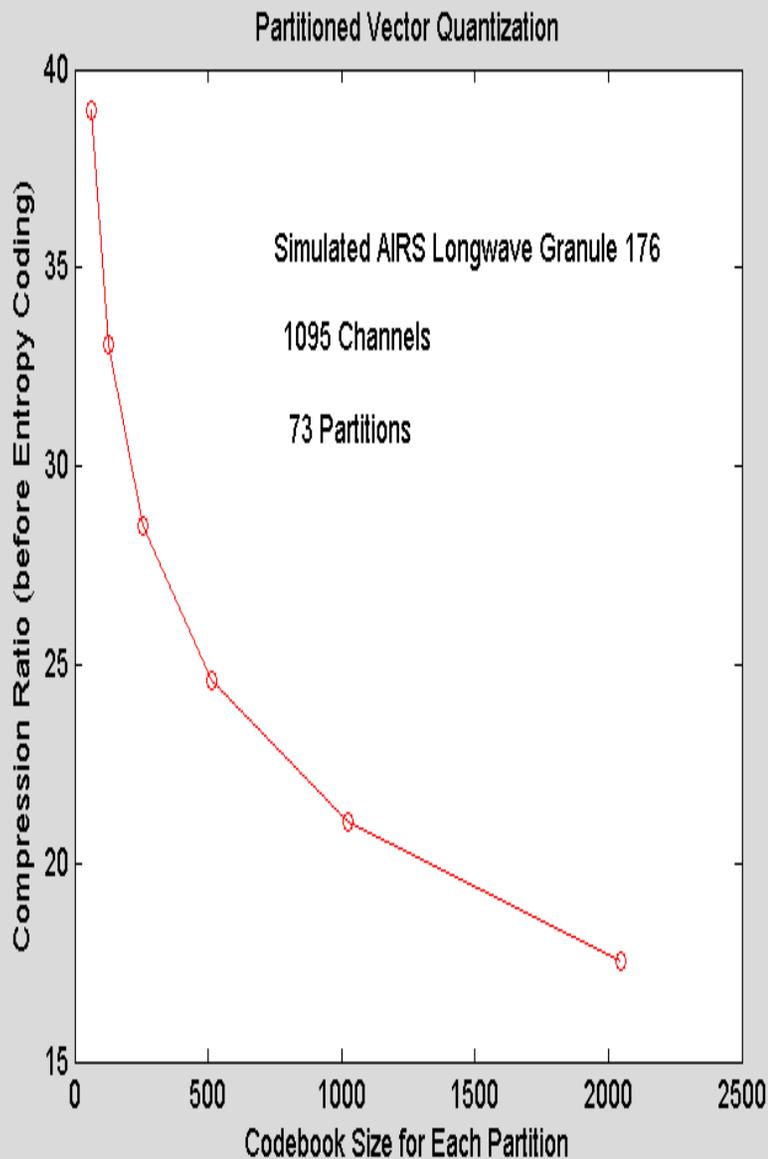
Simulated (forward calculated) LW/MSW Data Cube

■ A 3D SPIHT Encoder for Any Data Size

■ A 3D SPIHT Encoder for Regular Data Size



# Partitioned Vector Quantization



# Summary

- What has been done
  - Nine 3D wavelet transforms tested on simulated and real data
  - Three types of 3D wavelet tree coding developed and tested
  - Regular-sized vs. irregular-sized wavelet tree encoders/decoder have been implemented
  - Both lossless and uniform lossy compression implemented
  - Arithmetic and Huffman coding implemented and tested
  - LPVQ implemented and investigated on simulated data
- What will be done
  - Implement other 36 integer wavelet transforms
  - Investigate non-uniform lossy compression
  - Investigate other promising lossless and lossy schemes
  - Perform additional shortwave data compressions
  - Perform compression studies on more real and simulated data
  - Perform more retrieval impact studies for lossy compression